AD NUMBER	
ADA800129	
CLASSIFICATION CHANGES	
TO:	**unclassified**
FROM:	**secret**
LIMITATION CHANGES	
TO:	**Approved for public release; distribution is unlimited.**
FROM:	**Distribution authorized to DoD only; Administrative/Operational Use; 31 OCT 1942. Other requests shall be referred to Office of Scientific Research and Development, Washington, DC. Pre-dates formal DoD distribution statements. Treat as DoD only.**
AUTHORITY	
SOD memo dtd 2 Aug 1960; SOD memo dtd 2 Aug 1960	

63646

Telegraphy Applied to TDS Speech Secrecy System - Final Report - October 31, 1942 (None)

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(None)

OSRD-1047

Oct' 42	Secret	U.S.	English	57	tables, diagrs, graphs

The advantages and disadvantages of incorporating tone telegraph transmission in the TDS speech secrecy equipment were investigated. Estimates were made of the degree of privacy afforded to telegraph signals applied to the TDS systems, and of the impairment of transmission caused by the TDS equipment. The relative privacy of scrambled telegraph signals as compared with scrambled speech signals was investigated. It was found that scrambled manual telegraph signals require at least as much time to decode as scrambled speech, so that the application of tone telegraph to TDS will not jeopardize its value for speech. The privacy of TDS for telegraph is not critically dependent on rates of hand sending and lengths of TDS time elements.

Copies of this report obtainable from CADO.

Electronics (3)
Communications (1)

Communication systems, Secret (23992.87)
Telegraph signals (92580)

C-3078

OSRD-P-5269

OSRD 1047

47

SECRET

63646

NATIONAL DEFENSE RESEARCH COMMITTEE

Final Report on Project C-55

TELEGRAPHY APPLIED TO TDS SPEECH SECRECY SYSTEM

Contract No. OEMsr-628

This report was prepared under a contract with the NDRC and therefore is the property of that organization. Accordingly, its circulation should be restricted to persons concerned with NDRC projects, whose work on such matters will be facilitated by it.

BELL TELEPHONE LABORATORIES,
INCORPORATED

SECRET

COMMUNICATIONS SECTION

NATIONAL DEFENSE RESEARCH COMMITTEE

OF THE

OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT

FINAL REPORT
ON
PROJECT C-55

TELEGRAPHY APPLIED TO TDS SPEECH SECRECY SYSTEM

C. W. CARTER

TRANSMISSION ENGINEERING DEPARTMENT

BELL TELEPHONE LABORATORIES, INC.

October 31, 1942

Contract No. OEMsr-628

Contractor: Western Electric Co., Inc.
195 Broadway
New York, N. Y.

Expiration Date of Contract: November 1, 1942

Serial No. 47

C-55 TELEGRAPHY APPLIED TO TDS SPEECH SECRECY SYSTEM FINAL REPORT - OCTOBER 31, 1942

SUMMARY

This project was undertaken to determine the advantages and disadvantages (if any) of incorporating means for tone telegraphy in connection with TDS speech secrecy equipment.

Questions of special interest were:

(1) Is TDS privacy less for telegraph than for speech? That is, will the use of telegraph through TDS tend to expose the code and thus reduce the privacy for subsequent telephone use?

(2) Is TDS privacy for telegraph critically dependent on rates of hand sending and lengths of TDS time elements?

(3) What impairment to telegraph transmission is caused by TDS?

(4) Is it feasible to apply machine telegraph sending to TDS systems?

The results of the tests indicate that:

(1) Scrambled hand-sent telegraph signals require at least as much time to decode as scrambled speech; there is therefore no reason to believe that the application of manual tone telegraph to TDS will jeopardize its value for speech.

(2) The privacy of TDS for telegraph is not critically dependent on rates of hand sending and lengths of TDS time elements.

(3) The limits of telegraph transmission are reached with about 5 db less thermal (random) noise with the TDS than without; this means that the range is reduced unless the signal strength is increased. The impairment is less for short than for long TDS time elements.

(4) Machine telegraph, both Boehme and teletypewriter, give generally legible, though not letter-perfect, results with single tone transmission, if care is used. Better results, though still not perfect, may be obtained with two-tone transmission.

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C-55 TELEGRAPHY APPLIED TO TDS SPEECH SECRECY SYSTEM

FINAL REPORT - OCTOBER 31, 1942

1. General Objectives

Project C-55 was undertaken to determine the advantages and disadvantages (if any) of incorporating means for tone telegraphy in connection with TDS speech secrecy equipment. Estimates were desired of the degree of privacy afforded to telegraph signals applied to TDS systems, and of the impairment of transmission caused by the TDS equipment. Probably the most important point was a determination of the relative privacy of scrambled telegraph signals as compared with scrambled speech signals. In addition, questions were raised as to the dependence of privacy on the rates of telegraph sending and on the length of the fundamental TDS time elements. It was desired also to investigate the effect that rates of sending and different TDS time elements might have on the quality of telegraph transmission, and to obtain information on the feasibility of applying machine telegraph to TDS systems.

2. Discussion of Results

The conclusions stated in the summary will be discussed in this section, under subheads covering the four principal questions. The specific tests and detailed data will be described in the succeeding sections.

2.1 Relative Privacy of Telegraph and Speech

In accordance with a request from the Signal Corps, arrangements for tone telegraph transmission were included in the TDS equipment which has recently been developed for the Army and the Navy. At the same time the question was raised as to whether the use of telegraph might not jeopardize the privacy of the device for speech. This was based on the idea that the TDS code might be recovered more quickly from scrambled telegraph signals than from scrambled speech signals. It was important to answer this question in order to determine whether restrictions would be needed on the use of telegraph.

The tests on that point, using the development models of TDS, have returned a negative answer. In fact the data, if taken literally, indicate a slightly greater privacy for telegraph than for speech. The differences in the average solving times are so small as to be negligible, however. The solving times both for telegraph and speech vary from sample to sample, so that some telegraph samples were solved more quickly than some speech samples, but the opposite was likewise true, and the range of variation was about the same for telegraph and speech.

However, there is a difference of another nature which is inherent. The two main steps in the restoration of scrambled speech are, first, that the code be found and, second, that the scrambled speech be reproduced through TDS equipment arranged for the unscrambling code. These steps also can be used for unscrambling telegraph, and if used there is no difference in the degree of privacy for speech and telegraph, since the times taken to ascertain the codes were the same. But another method might also be used for telegraph. If an oscillogram or a paper trace were made of the entire scrambled message, then solution of the code would supply the formula according to which the trace should be cut up and reassembled. If this were done for speech, the result would still be unreadable without fairly elaborate equipment; but a reassembled telegraph trace could be read by visual inspection of the dots and dashes.

As a practical matter this difference appears to be of little importance, as the following calculation indicates:

> At 25 words per minute, a 100 word message takes 4 minutes, or 240 seconds. At 0.75 seconds per TDS cycle, this would cover 4/3 x 240 = 320 TDS cycles, or supply 20 x 320 = 6,400 TDS elements for manipulation. If the trace were run so as to allow a quarter of an inch to each element, or 48 elements to the foot, which would be extremely compressed, the trace would need to be 6400/48 = 133 feet long. Even with practice and concentration probably at least a minute would be needed to reassemble each cycle, what with the manual labor of cutting and pasting, or 320 minutes; that is, it would take about 5 hours for one person to recover a 4 minute message. Additional people or supplementary equipment would, of course, reduce this time.

Thus, while the sense of the telegraph message can be recovered with less elaborate equipment than is needed for speech, the amount of clerical work involved would constitute a protection lasting longer than the privacy time which should normally be associated with a fixed code TDS system.

2.2 <u>Dependence of Privacy on TDS Time Elements and Rates of Hand-Sending</u>

That the privacy of telegraph signals applied to TDS might be dependent on the TDS time elements is suggested by the fact that if TDS elements are very long or are very short the signals will not be scrambled and therefore not be private. For example, if a time element were 5 minutes long any message shorter than this would not be scrambled. At the other extreme, if the time element were 1 millisecond long then the scrambling which would take place would be internal within the dots and dashes and while the signal might be made somewhat coarse its essential characteristics would not be changed. Since we know that for time elements in between these extremes the signal is scrambled, it is evident that the length of the TDS time element has a bearing on privacy. A curve of privacy plotted against TDS time elements would reach zero at the extreme times mentioned above and would pass through a maximum at some point between. The object of the tests in the present project was to find whether this maximum occurred in the range of practical TDS time elements and whether it was critically affected by the TDS time elements.

To investigate this matter, a laboratory model was used with TDS elements of 22 milliseconds, 33 milliseconds and

48 milliseconds. An element of 48 milliseconds is about as long as would be useful in a practical device, since with enough TDS elements to permit a sufficiently mixed up code an element length greater than 48 milliseconds would give too great an overall delay to the system. The 33 milliseconds element is approximately the same as the element used in the development models for the Army and the Navy (37.5 milliseconds). The 22 milliseconds element is probably shorter than could be considered in a practical device when the requirements of synchronism are kept in mind.

It happens that this range of TDS time elements lies in the range covered by the duration of telegraph dots as used practically. A common fundamental assumption covering the time relations in telegraphy is that for hand sending at 25 words a minute there is a maximum of approximately 10 dot-cycles per second, so that a unit space has a duration of 50 milliseconds. It may be recalled also that a dot is one unit space long, a dash is 3 unit spaces, that dots and dashes within a letter are separated by one unit space, that the interval between letters is 3 unit spaces and that the interval between words is 6 unit spaces. With a relatively unskilled sender, using a rate of 12 words a minute, the duration of the unit space is about 100 milliseconds; with rapid hand sending the duration of the unit space may be as short as 30 milliseconds. With hand sending there are, of course, wide individual variations from the prescribed time relations. With machine sending the unit spaces are considerably shorter. Using the Boehme equipment, which sends the continental Morse code mechanically, rates from 60 words a minute, with a corresponding duration of unit space of 20 milliseconds, up to several hundred words per minute, are not uncommon. Teletypewriter, which is based on a different type of code, commonly is operated at a rate of 60 words per minute, and a unit marking space is nominally 22 milliseconds long. It will be seen that with the TDS time elements mentioned above all dashes and nearly all dots from hand-sending will be chopped up by the TDS equipment.

The test results indicated that privacy of hand-sending was not importantly affected by the length of the TDS time elements in the range studied. With the 33 and 48 millisecond TDS elements there was no significant difference in the times required to ascertain the code from records of the scrambled telegraph signals. With the 22 millisecond TDS element slightly more time was required, but it is believed that this time difference was not fundamentally related to the TDS interval. It was more probably a result of the somewhat inconvenient sizes of oscillographic records which had to be studied. By modifying the equipment this inconvenience could be overcome. There appears, therefore, to be no basis in these tests for recommending a change in the time element of the TDS to be used by the Army and the Navy.

Tests made to study the effect on privacy of different rates of hand sending gave results which provide no reason for making a specific recommendation as to a preferred speed. The average rates used in these tests were about 15, 20 and 25 words a minute. The results indicated some slightly greater difficulty in ascertaining the scrambled code with the slow sending than with the medium and fast sending but the differences are not believed to be of practical importance.

2.3 Quality of Manual Telegraph Transmission

The process of chopping up telegraph signals in time, then scrambling these chopped up elements, transmitting them and reassembling them, naturally carries with it something of an impairment in the quality of the overall transmission. Experienced telegraphers have characterized TDS transmission as being "rough but readable". With the machines in proper synchronism, and with moderate amounts of line noise, there is no difficulty in copying the message correctly. Tests were made therefore to see whether limiting telegraph transmission was reached sooner with the TDS equipment inserted than without the TDS equipment. The limit of transmission was found by adding thermal noise to the line. Thermal noise has a practically uniform frequency spectrum and is similar to the type of noise which is produced by amplifiers when turned up to their maximum gain.

With the TDS omitted from the circuit, the noise was increased until the amount could be found which caused skilled telegraphers to make 50 per cent errors even when sending each word twice. This is a fairly critical reference point, since reduction of the noise by 3 db from this value permits the signals to be received almost without error and an increase of the noise by about 3 db from this value blots out the transmission almost entirely. After the noise causing 50 per cent errors without the TDS was determined, the TDS was inserted and it was found that transmission was impossible. The noise was therefore reduced until the amount of noise was found which again gave 50 per cent errors with double sending. With a 33 millisecond TDS element in the Model B TDS this reduction in the tolerable noise was about 6.5 db, and this 6.5 db is one measure of the impairment to transmission caused by the Model B TDS. A similar, but less thorough, test along the same lines was made with the development model (D-150285). The impairment found in this case was about 3 db. Combining the results of the tests with the two models it is concluded that the effect of TDS equipment is to cause the telegraph transmission limit for noise of the thermal type to be reached with about 5 db less noise than is the case without TDS. This means that to maintain the same range in the presence of noise of this type the signal strength would need to be increased by 5 db.

The same test with a 48 millisecond element in the Model B TDS gave a somewhat larger impairment, about 8 db, but with the 22 millisecond element in the Model B TDS the impairment was smaller, on the order of 3.5 db. From the point of view of overall manual telegraph transmission, therefore, a short TDS element is to be preferred to a long TDS element.

Brief tests were made with the development model (D-150285 TDS) in order to determine whether telegraphy could be carried on under more adverse conditions than telephony. In this case, also, thermal noise was introduced into the receiving TDS element and increased until the transmission limit had been reached for telegraph signals. Leaving the noise at this limiting value, speech was attempted through the system but it was discovered that even when the talker shouted, the listener was not aware that talking was going on. The noise had to be reduced at least 8 db before parts of a telephone conversation could be understood, and substantially more before the entire conversation was intelligible. Other types of noise, such as ignition and static, might modify this result because of their different reactions on the start-stop mechanism. However, in the case of thermal noise an appreciable margin for telegraph signals over speech is indicated.

Telegraph tests were made with the laboratory model in which the commutator brush of the receiving TDS unit was displaced by various amounts relative to the commutator brush of the transmitting unit. Small displacements were easily noticed by the resulting roughening of the tone. This was caused by the insertion of small bits of marking signal into spaces and by corresponding interruptions of marking signal in the dots and dashes. As a matter of judgment it was agreed that, with a 33 millisecond TDS time element, synchronism errors of 10 per cent of a TDS time element, or 3 milliseconds, seriously impaired the quality of transmission; and that with 15 per cent lack of synchronism, or 5 milliseconds, the quality was extremely poor. It was found, however, that with aural reception this apparently large impairment could be overcome by practice. In this respect, the aural reception of telegraph signals resembles the reception of speech. Tests with speech, when the commutators were also about 15 per cent out of synchronism, showed that while the number of articulation errors was increased and the quality was bad it was still possible to talk if effort were used. For both telegraph and telephone, however, lack of synchronism of more than about 5 per cent of a TDS element should be avoided. With a 37.5 millisecond element this means that the synchronism should be kept to within 2 milliseconds at the two ends.

2.4 Machine Sending

Tests of machine telegraph sending with the laboratory model have indicated that readable, but not letter perfect, results can be obtained, but that transmission may be unsatisfactory unless special precautions are taken. The principal source of trouble to be guarded against appeared to be cyclic reductions in amplitude of the marking signal caused by imperfections in the magnetic tape, but care had also to be taken to avoid faulty operation from the switching and tape noises.

Preliminary tests indicate that these difficulties can be reduced by careful line-up and adjustment of the telegraph receiving equipment, and by the use of a detector with a strong limiting action to smooth out the inequalities in transmission of the marking pulses. Another plan which has been tested briefly, and with favorable results, uses two tone telegraphy, one frequency for marking and the other for spacing, with special relay and filtering arrangements to minimize detrimental effects of level changes and other disturbances. Since, when care was used, it was possible to obtain reasonably good copy with the laboratory model of TDS, further refinement of this result by two tone or other methods did not seem justifiable until the final machines, including their start-stop synchronizing arrangements, are available for test.

No privacy tests have been made with machine sending, but if the same methods were used to ascertain the TDS codes from the scrambled signals as are used at present with hand-sending, there is no reason to believe that privacy for machine sending would differ materially from that for hand-sending. This, however, should not be taken for granted and should be tested with the D-150285 TDS if further development work on machine sending is carried out.

3. TDS Models Tested

The TDS equipment developed for the Army and Navy has been coded as the Western Electric D-150285 TDS Equipment and for convenience will be referred to by its code number. The Army and the Navy models differ only in minor respects having to do with the input impedance arrangements for the telephone sets. This equipment is a device with a 20 element commutator and nine pickup coils, arranged to provide independent coding of the odd and even commutator segments. The fundamental TDS time element is 37.5 milliseconds, giving an overall delay of .75 second. The input circuit of this device is provided with a jack connection for a telegraph key and a switch which when thrown permits the transmission for telegraph purposes of an internal tone which was built into the equipment for motor speed control purposes. The frequency of this tone is 720 cycles per second. The D-150285 equipment maintains synchronism by transmission of a 2000 cycle per second start-stop pulse once per revolution of the commutator.

Most of the testing has been done with a laboratory model which was built as a successor to the 5 element model originally developed under the first N.D.R.C. contract on this subject. This second model, used in the present project, is referred to as Model B. It has a 14 element commutator and 13 pickup coils. There are seven code switches so arranged as to scramble the first seven commutator elements as a permutation of 7 digits, and at the same time to scramble the second seven commutator elements into that particular permutation of 7 digits which decodes the permutation used with the first seven commutator segments. It may therefore be called a code plus converse style of TDS based on a 7 element code. The two units of Model B TDS are mounted on a single relay rack and are driven by a single motor with positive mechanical coupling between the units. By changing pulleys in the drive, the speed and hence the TDS time elements can be varied.

It is the opinion of most engineers who have listened both to the D-150285 TDS and the Model B TDS that the two devices are generally comparable as to quality of reproduction of speech, and as to background noise (except for the absence of synchronizing tone in Model B). The D-150285 TDS equipment differs from the Model B TDS, however, in the greater complexity of its codes.

The action of the Model B TDS machine on a hand-sent telegraph signal is illustrated by the oscillograms shown in Figs. 4A and 4B. This contains the word "Paris," sent at about 20 words per minute. The top string in each record shows the signal which was sent. The middle string shows the signal scrambled according to the code 2473165. The bottom string shows the restored signal. The time scale is given by the vertical lines; the strongest lines are 50 milliseconds apart, the medium lines are 10 milliseconds apart and the finest divisions represent one millisecond. Since the 33 millisecond TDS interval was used in this record, the restored signal has been delayed about 470 milliseconds (closer figures are 33.4 and 468 milliseconds, respectively).

The particular pattern into which the signal has been scrambled depends, of course, on how the signal happened to line up with the TDS cycle, and would, in general, be different for each sending of the same word. In this case the second dash of P has been split into several ragged dots; the letter A has become dot-dot-dash-dot and might be read as F, etc.

4. Privacy Tests with Hand Sending

4.1 Direct Listening

Using the Model B TDS, experienced telegraphers attempted transmission through only one of the units; that is, they attempted to read the message when listening to the scrambled signals. A variety of codes were tried, ranging from some with relatively few displacements of the scrambled elements up to codes having a high degree of scrambling. In no case was it found possible to read the message correctly even when single words were repeated as many as five times. The opinion was expressed that the scrambled signals gave the impression of telegraph signals even though scrambled, but suggested the wrong characters to the telegrapher.

4.2 Recordings of Scrambled Telegraph Signals

Four phonograph records were made of samples of scrambled telegraph signals in the course of this project. These are listed on an attached table. These records have been used by engineers working on Project C-43 in order to study the privacy of the telegraph scramble. It is proposed to leave these recordings, including the master records, in the files of C-43.

4.21 Privacy of Telegraph Compared with Speech - D-150285 TDS

Phonograph records were made both of samples of speech and of samples of telegraph, using the D-150285 TDS. These were analyzed by the personnel engaged on Project C-43.

The methods which were used to ascertain the TDS codes from these samples of scrambled speech and telegraph signals need not be described here, since reference may be made to the reports of Project C-43. It is sufficient to state that certain preliminary work resulted in an oscillographic type of film ready to be cut up and reassembled in the correct order. In the data given below the times are given in minutes for this process of reassembling the films correctly. The time taken for the preliminary processes is not given. It should be noted, therefore, that percentage comparisons between the various averages are of little value since each figure should be increased by the number of minutes corresponding to this preliminary work.

The detailed results for this comparison of solving times for speech and telegraph are given in the following table. The individual results for each sample, as obtained by each of two persons, are given in order to illustrate the variation from sample to sample. This variation is of such a magnitude that no importance need be given to the fact that the samples of speech were solved more quickly, by 1.0 minute, than the samples of telegraph. If sample No. 6 of speech, which stands out for the quickness of its solution, is omitted, the averages are exactly the same for speech and telegraph. Likewise, while some speech samples were solved in less time than any telegraph sample, the difference in the ranges of times is slight when

SCRAMBLED SPEECH AND TELEGRAPH SIGNALS
COMPARISON OF SOLVING TIMES IN MINUTES
D-150285 TDS

Speech			Telegraph		
	Solving Times			Solving Times	
Sample	DFH	CEM	Sample	DFH	CEM
1	19	21	1	20	10
2	20	11	2	17	17
3	18	12	3	15	12
4	20	21	4	19	13
5	14	7	5	19	15
6	6	8	6	19	18
			7	15	13
			8	12	14
			9	18	17
Averages	16.1	13.3		17.1	14.3
Grand Averages	14.7			15.7	

speech sample No. 6 is omitted. Recalling also that the actual solving times are greater by the processing time, which is the same in either case, the conclusion from these tests is that with the present methods there is no material difference in the privacy of speech and telegraph through TDS.

4.22 Variation of Privacy with TDS Time Elements and Hand-Sending Speeds - Model B TDS

Using Model B TDS, three phonograph records were made with a total of 45 samples of scrambled hand-sent telegraph signals. These were so arranged as to yield 15 samples with each of three TDS time elements: 22 milliseconds, 33 milliseconds and 48 milliseconds. They were also arranged to yield 15 samples of each of three sending speeds, slow, medium and fast. The sending speeds naturally varied somewhat about the averages, which turned out by measurement to be 15, 19 and 23 words per minute. A different code was used with each of the specimens. Two telegraph operators took part in the tests, dividing the sending almost equally. As each telegrapher sent, the other telegrapher listened at the output of the second TDS unit in order to check that the scramble which was being recorded was set up correctly, as evidenced by its being properly unscrambled by the receiving unit. The texts used consisted of sentences of from 10 to 15 words, so that the samples varied in length from 15 to 30 seconds.

The solving method was the same as that used in the preceding tests. In this case, also, the data given are the times in minutes for the process of reassembling the films correctly without the time taken for the preliminary processes.

The samples of scrambled signals were divided first into two batches each having a full selection of the different variables. Solution of one of the batches was completed before work on the other was begun. The results obtained with the two batches were compared to see whether evidences of a practice effect were present. The results were:

Average for First Batch - 9.6 Minutes

Average for Second Batch - 9.7 "

The closeness of these averages indicates that the person carrying out the work (C.E.M.) was well skilled in the process. The data were therefore combined and averages were taken of the various sub-classes to be studied. The average in each sub-class represents 5 samples, except in two sub-classes which contained 4 samples each. The average results may be shown compactly in a three-fold table:

SOLVING TIMES FOR MODEL B TDS - MINUTES

Telegraph Sending Speeds	TDS Time Elements - Milliseconds 48	33	22	Averages
Slow	7.2	8.8	16.8	10.9
Medium	7.8	8.4	9.0	8.4
Fast	12.3	6.0	11.7	8.4
Averages	8.9	7.7	12.6	9.7

The effect of the length of the TDS element on the solving times is shown by the averages at the bottom of the table. It will be noted that the solving times are not much different for the 48 and the 33 millisecond elements while for the 22 millisecond element the solving times are about 4 minutes greater. However, considering that the preliminary processing time has not been included in the figures given, this 4 minute difference is of less importance than would appear on a percentagewise basis. Furthermore it is the opinion of the engineers working on project C-43 that the greater solving time was not so much a characteristic of the TDS as it was a result of certain conditions in the equipment used. These are being modified in later models. In other words, there appears to be no reason to conclude that modification of the fundamental design of the TDS machines to a shorter time element would result in materially greater protection to the scrambled messages.

The effects of different telegraph speeds may be compared by examining the averages in the last column. It will be seen that the average times for the medium and fast sending were identical, while from 2 to 3 minutes more were required to solve the slow sending. This may possibly be a result of the fact that in the process of the solution the same number of TDS cycles was used from each sample, so that with slow sending there was somewhat less material to work with, inasmuch as there were fewer dots and dashes present on the record than with fast sending. However, when the subdivisions of the data are examined it would appear that the added time was associated almost entirely with the 22 millisecond TDS element and that for the average TDS element there was very little difference as between the sending speeds at the slow and medium rates. In any case, however, the differences among the sending speeds appear to be so small when the preliminary time is allowed for as not to be of material concern.

It is of some interest that the average solving time for the Model B TDS, using the 33 millisecond TDS interval, was 7.7 minutes, while for the D-150285 TDS, having a comparable time element, the average time, for the same person, was 14.3 minutes. This presumably reflects the greater complication of the 20 element, widely dispersed, interlaced codes of the D-150285 TDS equipment, as compared with the simpler code plus converse based on permutations of 7, used in the Model B TDS.

4.23 Variation of Privacy With Inversion Numbers - Model B TDS

In a TDS code which is a permutation of successive numbers, the degree of scrambling may be characterized by the "inversion number". This is a measure of the number of simple interchanges of adjacent elements which is required to rearrange the elements in their correct order. For example consider the code 2134567. In this code the only scramble is an interchange of the digits 1 and 2. It therefore has an inversion number of 1. Such a code naturally would be of little value for privacy purposes. A more mixed-up code is 4271365. This may be returned to its correct order by interchanging neighboring digits in 9 operations. It therefore has an inversion number of 9.

With a code based on permutations of 7 numbers the maximum inversion number is 21. It may be shown that a code and its converse, or decoding permutation, have the same inversion numbers. It may also be shown that if the reverse code, 7654321, is applied to any scramble, the resulting scramble will have an inversion number equal to the maximum minus the original inversion number. Thus a very high inversion number can be made very low by using the reverse code, so that inversion numbers around the average may practically be more safe than very high ones. The average in the present case is 10.5.

In the test described in the previous section, the samples of scrambled telegraph signals were given equal numbers of codes having inversion numbers of 9, 10, 11, 12 and 13.

While this is not a very wide range of inversion numbers, it is of some interest to examine their effect on the times required to reassemble the TDS patterns. This is shown in the following table.

SOLVING TIMES FOR TDS - MINUTES

Inversion No.	Average Time
9	8.4
10	8.1
11	10.4
12	11.1
13	10.0

It will be seen from these data that, while the variation in solving time is relatively small and irregular, there is some indication that more time is needed for the higher than for the lower inversion numbers. The differences, however, are so slight as to be of little practical importance.

4.3 Transient From Keyed Telegraph Tone

In the tests described in Sections 4.22 and 4.23 an oscillator was used which gave a negligible transient when keyed by a telegraph key. Some preliminary tests were also made with an oscillator built to simulate a Signal Corps telegraph oscillator. This gave noticeable transients both at the beginning and the end of a telegraph mark. This is a characteristic which it is understood that many telegraphers prefer. The opinion has been expressed that under difficult noise conditions the building-up and dying out at the end of each mark provide helpful clues in reading a message.

From the point of view of privacy, however, these transients are undesirable. Transients provide information which differentiates the ends of the telegraph marks from the cuts caused by the switching of the TDS equipment. This information can be turned to account both in the preliminary work of marking off the TDS time intervals on the oscillographic traces and in reassembling the films in their correct order. A comparison of the two types of signals is given in Fig. 5.

The transients from the internal tone used for telegraph in the D-150285 TDS were so slight as not to be a factor in the solution of the codes.

5. Privacy of Machine Sending

As discussed more fully elsewhere, transmission which is fairly satisfactory, though not letter perfect, can be secured with machine sending through TDS, provided that the telegraph receiving equipment is carefully lined up to minimize the detrimental effects of transmission variations through the TDS equipment.

The kinds of scrambled signals produced by Model B are illustrated on Fig. 9. The results with teletypewriter at 60 words per minute are shown in two forms: the jumbled output of the typing machine and also as an ink trace taken by a Boehme receiver. The scrambled results with Boehme sending at 150 words per minute are shown in the lowest tape. In both cases the original text was "The quick brown fox jumped over the lazy dog's back 1234567890 BTL sending". Privacy tests to determine solving times have not been made with machine sending, but are recommended when the D-150285 TDS equipment becomes available.

6. Quality Tests With Hand-Sending

6.1 Judgment of Skilled Operators

Experienced telegraph operators were asked to give their opinions with respect to the quality of the restored telegraph signals. These opinions have been summed up in the statement that the tone was "rough but readable". On the basis of the RST scale, used by the American Radio Relay League, the opinion was given that the tone through Model B would rate about 4 to 5 as to "readability" on a scale of 5, and about 4 on a scale of 9 as to "tone" (the item of "strength" was adjustable).

The reasons for opinions of this sort may be seen on the oscillograms shown in Figs. 4 and 5, which were taken with Model B. The middle trace shows that the different pickup coils of this device are not uniform in their efficiency in the sending machine and it may be stated that there is a similar variation in the receiving machine. Magnetic tapes are not uniform and cyclic variations occur from the end joint in the tape and from the clamping arrangements. Some of these variations cause noise; others affect the strength of transmission. Some background noise is also contributed by the tape and by the action of the brush in moving from segment to segment of the commutator in the process of switching.

It was pointed out in the discussion that relative displacements of more than a few per cent of a commutator segment between the transmitting and receiving commutator brushes gave an impression of very poor transmission. The reason for this is illustrated in Fig. 6. For these oscillograms the brush of the receiving commutator was set so as to lag behind the brush of the transmitting commutator by about 15 per cent of a segment or nearly 5 milliseconds. The elements missing from the telegraph marks and the corresponding added short spurts of tone may be seen in the picture of the lowest string, showing the restored signal. These added bits of tone, while only a few milliseconds in duration, appear to be prominent enough to suggest to the telegrapher the presence of a dot.

6.2 Effects of Thermal Noise on Telegraph - D-150285 TDS

The circuit used to study the limiting effects of thermal noise on telegraph transmission, using the D-150285 TDS equipment, is shown schematically in Fig. 1. As mentioned in the discussion, the procedure adopted for this purpose was to introduce thermal noise between the transmitting and receiving TDS units and to increase this thermal noise until a substantial number of errors was made even when each word was sent twice.

The two telegraph operators who took part in these tests alternately transmitted and received. The test material consisted of lists of 30 English words selected at random from printed matter, omitting proper names and articles. Each word was sent twice before going on to the next word, as is frequently done under difficult circumstances. In the data below, and in the next section, the first sending of each word has been scored separately from the second sending. As might be expected, there are materially fewer errors in the second sending; similar final conclusions are drawn from each sending, however.

The thermal noise and the signal strength were measured with standard volume indicators, or with other measuring devices having essentially similar dynamic characteristics. The measurements have been reduced to "VU"; this is a db scale on which 1 milliwatt of steady testing power dissipated in 600 ohms gives a reading of zero. Since the noise measurement is a function of band width, attention is directed to the fact that the noise covered a frequency range from about 250 to 5000 cycles per second. The signal was adjustable to a convenient level, so that the controlling factor was the margin between the noise and the signal. This margin has been shown as a noise-to-signal ratio in db, positive numbers denoting a noise measurement greater than the signal measurement.

TRANSMISSION LIMITS IN TERMS OF THERMAL NOISE

D-150285 TDS

Test No.	Operators Sending	Operators Receiving	Noise VU	Signal VU	Noise to Signal db	Per Cent Errors First Sending	Per Cent Errors Second Sending
1	HSW	ECT	+3.5	-1.0	4.5	83.3	80.0
2	ECT	HSW	+3.0	-0.5	3.5	83.3	53.3
3	HSW	ECT	+3.5	-1.0	4.5	83.3	53.3
4	ECT	HSW	+3.5	+0.5	3.0	87.7	43.3
		Averages	+3.4	-0.5	3.9	84.2	57.5

The results of this test with the D-150285 TDS are shown on the adjacent table. Four tests were made, with reasonable agreement among them. Since 57.5 per cent errors were made with the second sending at an average noise-to-signal ratio of 3.9 db, it seems reasonable to conclude that the 50 per cent error point would have been reached at a noise-to-signal ratio of about 3.5 db. This may be compared with the value of 6.6 db obtained without the TDS, shown in the table in the next section, which indicates that the D-150285 TDS caused an impairment to transmission of approximately 6.6-3.5 = 3.1 db. That is, with thermal noise, the limits of manual telegraph transmission with the D-150285 TDS are reached under noise conditions about 3 db less severe than without the TDS. Or, to maintain the same range in the presence of thermal noise the signal strength should be increased about 3 db. A similar test with Model B is described in the next section, in which for a comparable TDS time element the impairment was found to be about 6.5 db.

It has already been mentioned in Section 2.3 that with the D-150285 model an appreciable margin was found for telegraph signals over speech in the case of thermal noise.

6.3 Variation of Quality with TDS Time Elements and Hand-Sending Speeds - Model B TDS

In the experiments on telegraph quality carried out with the Model B TDS, it was possible to study the effect on transmission of varying the length of the TDS time elements. These tests, which have been summarized in Section 2.3, were carried out with the circuit arrangement shown schematically in Fig. 2. This is similar to the arrangement used with the D-150285 TDS, with the exception that an external oscillator was used as the source of telegraph tone. The testing material and the method used, slow double sending, were the same as in the preceding section.

The results of these tests, averaged for the two operators, are given in Fig. 7. The upper diagram shows the data for first sending, the lower for second sending. When first sending and second sending results are compared it will be found that the curves are nearly parallel and shifted from 1 to 2 db along the noise-to-signal axis. The steepness of the curves is characteristic of telegraphy; with a given signal strength a change in the thermal noise of 5 or 6 db is enough to take the data from substantially no errors to 100 per cent errors.

An evaluation of the effect of variation in the time elements of the TDS on transmission is obtained by comparing the noise-to-signal ratios for some selected value of errors. In the following table the 50 per cent point was chosen.

NOISE LIMITS WITH AND WITHOUT TDS

VARIOUS TDS TIME ELEMENTS

Circuit Condition	Noise to Signal Ratio at 50 Per cent Error - db: First Sending	Second Sending	Displacement From Reference Circuit - db: First Sending	Second Sending	Average
No TDS	+5.5	+6.6	-	-	-
TDS-22ms Element	+2.0	+2.8	3.5	3.8	3.6
TDS-33ms Element	-1.2	+0.2	6.7	6.4	6.5
TDS-48ms Element	-2.3	-1.2	7.8	7.8	7.8

It will be seen from this table that the insertion of the TDS had, with each value of time element, an adverse effect on the transmission of the signals since 50 per cent errors were made with less noise when the TDS was used than when it was omitted. The amounts of the impairments varied. With the average length of TDS element 6.5 db less noise could be tolerated than with the reference circuit. With the 48 millisecond element the difference was about 8 db and with the 22 millisecond element the difference was about 3.5 db. These results are shown graphically on Fig. 8. The tests indicate that from the point of view of transmission quality a short TDS time element is better than a long TDS time element. It should be pointed out at the same time, however, that shortening the TDS element increases the difficulty of maintaining exact synchronism and no recommendation is made that the basic element of the TDS be changed.

Brief tests on a similar basis were also made with the TDS receiving commutator brush arranged to lag behind the transmitting commutator brush by about 15 per cent of one segment. As pointed out above, this gave the impression of very poor transmission when no noise was present. These tests were made to evaluate this difference in terms of the limit of transmission with thermal noise. The tests were made with a 33 millisecond TDS time element. The result was unexpected, since the impairments derived exactly as in the preceding case were, if anything, less with the devices out of synchronism than when correctly adjusted. This is shown by the following values for noise to signal ratio giving 50 per cent errors:

	First Sending	Second Sending
TDS in synchronism	- 1.2	+ 0.2
TDS out by 15 per cent	- 1.2	+ 1.5

With the machine out of synchronism an average impairment of 5.9 db is obtained, as compared with a value of 6.5 db for the correctly adjusted device. The explanation for this curious result is that the operators, in earlier judgment tests, had become interested in the odd and broken impression given by the lack of synchronism and had practiced to the point of overcoming it. It can be definitely stated that when first given the out-of-synchronism condition they had found that copying a message was difficult even in the absence of noise. It may be concluded that some lack of synchronism can be tolerated if compensating effort is used, but it should be avoided as far as possible so as not to require this additional skill.

7. Quality Tests with Machine Sending - Model B TDS

Tests were made with machine sending using both Bell System start-stop teletypewriters and Boehme equipment. The teletypewriter operated at a standard speed of approximately 60 words per minute. The Boehme equipment, which transmits the continental Morse code, was operated at 50, 100, 150 and 200 words per minute.

The testing arrangements are shown schematically on Fig. 3. In this case the machine sending and receiving equipment was located at 180 Varick St., which required trunking to and from 463 West St., a distance of about 0.7 miles, to pick up the TDS. Transmission in most of the tests was carried out with a single tone, usually of 1785 cycles per second, though some tests were made with a frequency of 1105 cycles per second. Some two-tone tests were also made, in which a tone of 2125 cycles per second was used for marking and a tone of 2975 cycles per second was used for spacing.

With the Model B TDS, the frequency used within the band from about 400 to 3000 cycles makes no particular difference. A word of caution is in order, however, concerning the application of external tones to the D-150285 TDS. Because of the filtering arrangements which must accompany the 2000 cycle start-stop synchronizing tone of the latter, tones of frequencies within the band from about 1750 to 2250 cycles per second will suffer considerable amounts of attenuation. It is doubtful, for example, whether the 1785 cycle tone mentioned above, would be found satisfactory with the D-150285 TDS.

The action of the Model B TDS in scrambling teletypewriter and Boehme transmission is illustrated in Fig. 9, to which reference has already been made in section 5.

The precautions needed in lining-up the telegraph receiving equipment for single-tone telegraphy consist in principle of striking a balance between two kinds of disturbing effects arising in the TDS. One affects the marking signal and originates in imperfections of the magnetic tape and inequalities in transmission among the various pick up coils. These cause variations in the received strength of the marking signal. If the telegraph receiving equipment is made relatively insensitive, the final recording relay of the Boehme will tend to react as to a space during the low phases of the marking signal, and the selectors of the teletypewriter will tend to pick out wrong characters. Such an adjustment will give a relatively "clean" space but at the cost of some errors from a varying level of the marking signal. The other kind of disturbance occurs during the spacing intervals, and originates in the clicks which also arise from imperfections in the magnetic tape, and to some extent from the switching actions in the TDS. If the telegraph receiving equipment is made so sensitive that a relatively "clean" mark is received some of these clicks are likely to be recorded as marking signals.

The best adjustment with Model B TDS appeared to be one in which the dips in steady marking signal as produced by the Boehme recorder were not greatly different from the peaks in a steady spacing signal. However, there appeared to be less tolerance to variations in the marking signal than to variations in spacing, so that the best adjustments were generally on the side of getting a clean marking signal.

The effects of various adjustments in single tone telegraphy are illustrated in Figs. 10 to 14 inclusive. In Fig. 10 the effects of two different poor adjustments on teletypewriter signals are shown, and in Fig. 11 are given the results with a balanced adjustment. In the top half of Fig. 10 the effect of concentrating on a relatively clean spacing signal is shown. The cyclic imperfections of the TDS appear as prominent dips in the steady marking tone, and there are many errors in the resulting copy.

A count of the errors with various testing conditions is given in the accompanying table:

ERRORS IN MACHINE TRANSMISSION

Model B TDS

Condition	Errors per Sentence: Teletypewriter 60 w.p.m. (a)	Teletypewriter 60 w.p.m. (b)	Boehme 150 w.p.m. (c)
Single Tone Transmission			
Spacing Interval Favored	20	23.5	20.5
Marking Signal "	5.5	7.5	15
Balanced Adjustment	6.5	6.5	8
Volume Limiter Added	1.0	1.0	5.5
Two-Tone Transmission	0.3	0.3	0.5

Note: (a) Errors caused by incorrect typewriter shift counted only once if succeeding characters were otherwise correct.

(b) All wrong characters counted.

(c) Counts of Boehme errors necessarily are affected by the judgment of the counter.

In the lower half of Fig. 10 the marking signal has been considerably cleaned up by increasing the receiving sensitivity, but now the peaks of noise are prominent in the spacing signal. The copy is considerably better than in the upper half, but still poor. In Fig. 11 it may be seen that the outstanding imperfections in the marking signal and the spacing signal have been approximately balanced. In this condition the copy in the upper half of Fig. 11 was produced. It represents another step in improvement over the results of the upper half of Fig. 10, but is about the equivalent of the lower half of Fig. 10. There are still six or seven errors per line.

A similar set of records is shown in Figs. 12, 13 and 14 for single-tone Boehme transmission. Figs. 13 and 14 differ only in that a rate of 50 words per minute was used in Fig. 13 and a rate of 150 words per minute in Fig. 14. The test sentence used with the Boehme is also "The quick brown fox, etc." It will be noticed, on studying the characters, that the mutilations are in general sufficiently separated that a correct reading could be made of a plain text message in which context would clear up ambiguities. Numerals, however, and enciphered messages might be subject to misinterpretation. As the table indicates, while the balanced adjustment did not appreciably improve the teletypewriter performance, there was a distinct improvement in the high-speed Boehme.

Records of a further experimental step toward improving the performance with machine transmission are shown at the bottom of Figs. 11, 13 and 14. To make these records the alternate receiving circuit shown in Fig. 3 was used.

This included a current amplitude limiter, which further tended to smooth out the transmission variations in the marking signal. The records, as compared with those obtained with the best adjustments without the limiter, are evidently cleaner and this is verified by the error counts shown in the table.

The very brief tests which were made using two-tone telegraphy, one tone for marking and the other for spacing, gave encouraging results. The error counts shown in the table represent 5 errors in 18 sentences with teletypewriter, and one error in 2 sentences with Boehme at 150 words per minute. A sample of the Boehme at 150 words per minute is given in Fig. 15.

With engineering attention given to the problem, the indications are that machine telegraph transmission can be successfully applied to TDS. It has not appeared desirable to pursue these refinements further with the laboratory model, however, since the D-150285 equipment is likely to have somewhat different characteristics and variations in factory products need to be considered. When the D-150285 devices become available, and if there is an interest in the application of machine telegraph to TDS, the development may be continued along fairly well indicated lines.

8. Record Of Tests

All of the tests from which results have been quoted above were carried out by members of the Bell Telephone Laboratories, Inc., at 463 West Street and 180 Varick Street, New York City. The detailed measurements are recorded in B.T.L. Laboratory Notebooks Nos. T-5534 and T-5853.

Report prepared by: C. W. Carter

Official Investigator: R. G. McCurdy

Att.
List of Phonograph Records
List of Figures
Figs. 1 to 15 incl.

Bell Telephone Laboratories, Inc.
463 West Street
New York, N. Y.

NDRC PROJECT C-55

PHONOGRAPH RECORDS OF TELEGRAPH SIGNALS

The recordings listed below were made on instantaneous recording disks. They are vertically cut at 33.3 r.p.m., from the inside out. If reproduced by a No. 7A reproducer they probably will be good for 25 playings, if by a No. 9A reproducer, about 15 playings.

1. Scrambled

   No. 6137 (Original) - 15 samples from D150285 TDS

   No. 6138 dubbed from No. 6137

   No. 6259 (Original) - 15 samples from Model B TDS, 48 millisecond time elements

   No. 6263 dubbed from No. 6259

   No. 6260 (Original) - 15 samples from Model B TDS, 33 millisecond time elements

   No. 6264 dubbed from No. 6260

   No. 6261 (Original) - 15 samples from Model B TDS, 22 millisecond time elements

   No. 6265 dubbed from No. 6261

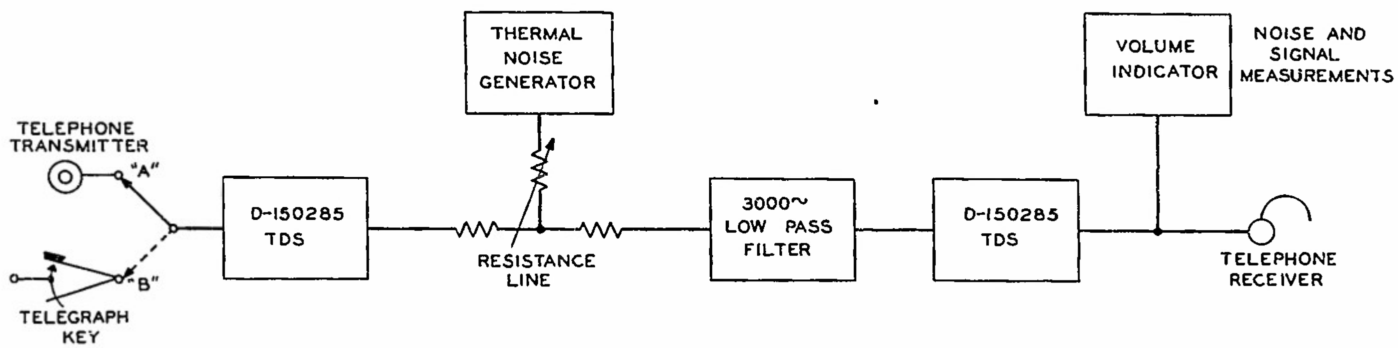
2. Restored

   No. 6262 (Original) - Restored signals from Model B TDS, 4 samples each with 22, 33 and 48 millisecond time elements; also 3 samples with no TDS

LIST OF FIGURES

N.D.R.C. PROJECT C-55

TELEGRAPHY APPLIED TO TDS SPEECH SECRECY SYSTEM



SCHEMATIC OF CIRCUIT TO DETERMINE MARGIN OF TELEGRAPH OVER SPEECH TRANSMISSION WITH D-150285 TDS

FIG. I

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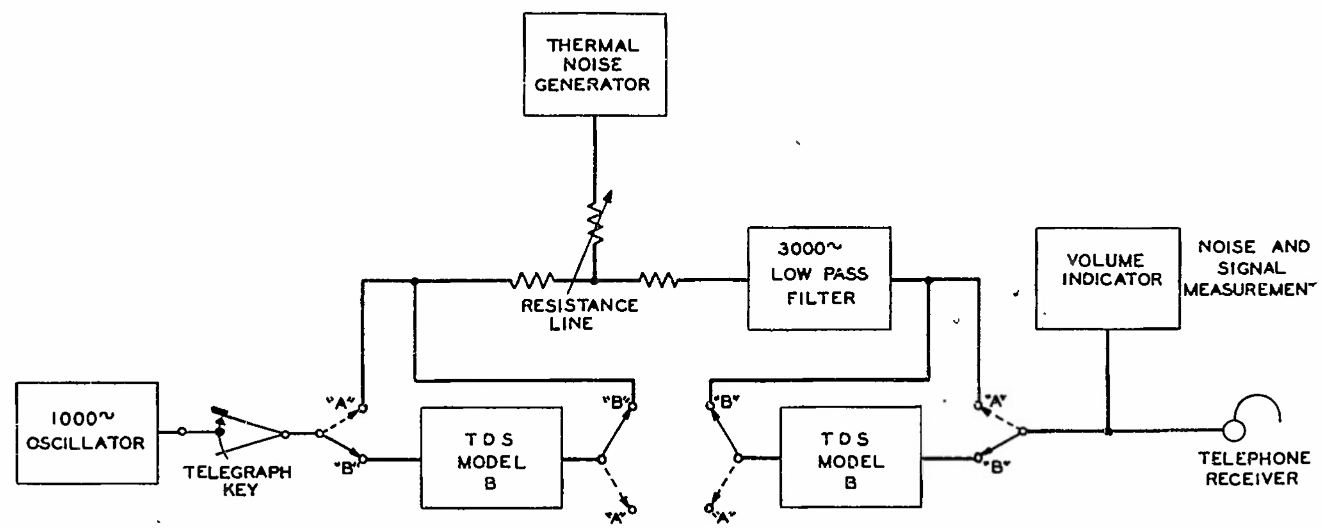
N. D. R. C. PROJECT C-55

TELEGRAPHY APPLIED TO TDS SPEECH SECRECY SYSTEM

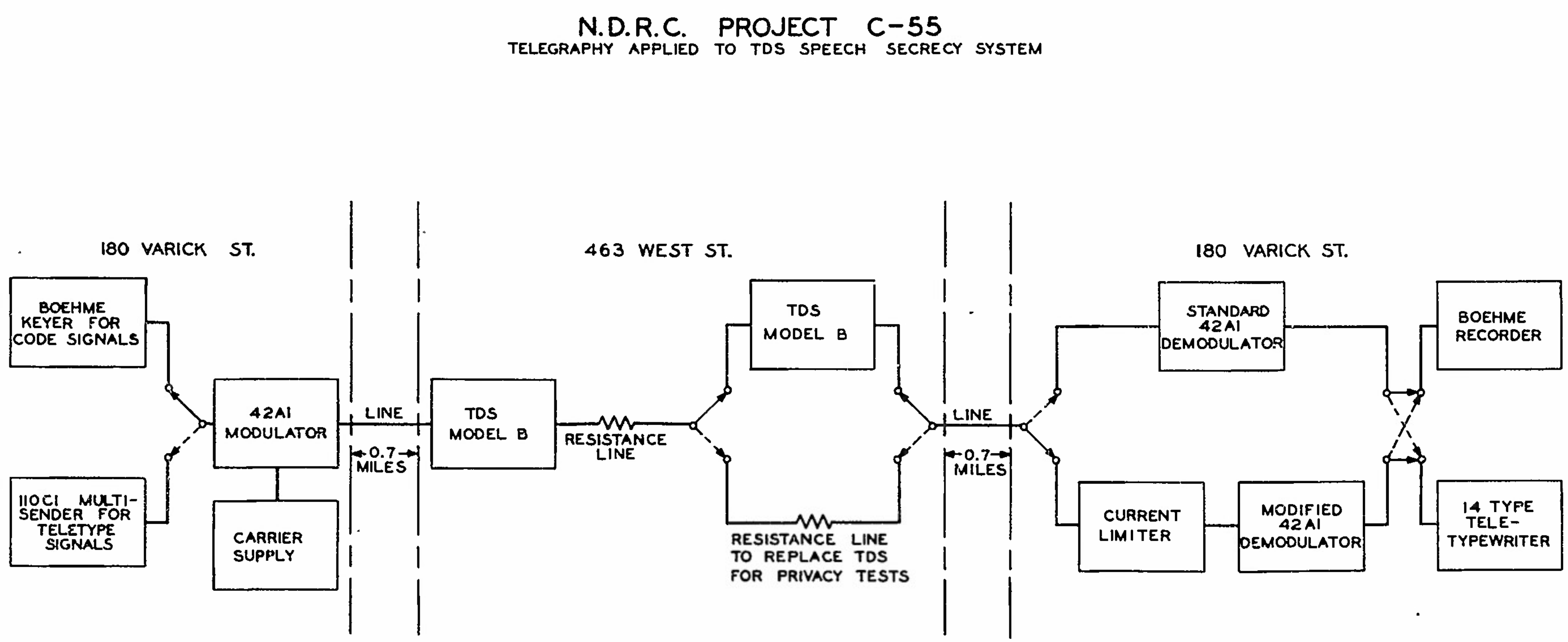


CONDITION "A". REFERENCE CONDITION: NO TDS, RESISTANCE LINE, THERMAL NOISE. (DOTTED POSITION OF SWITCHES)
CONDITION "B". TDS, RESISTANCE LINE, THERMAL NOISE. (SOLID POSITION OF SWITCHES)

SCHEMATIC OF CIRCUIT USED TO DETERMINE TRANSMISSION IMPAIRMENT OF MODEL B TDS

FIG. 2

SECRET



SCHEMATIC OF CIRCUIT USED TO INVESTIGATE THE APPLICATION OF MACHINE TELEGRAPH SENDING TO MODEL B TDS

FIG. 3

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N.D.R.C. Project C-55
Telegraphy Applied to TD3 Speech Secrecy System

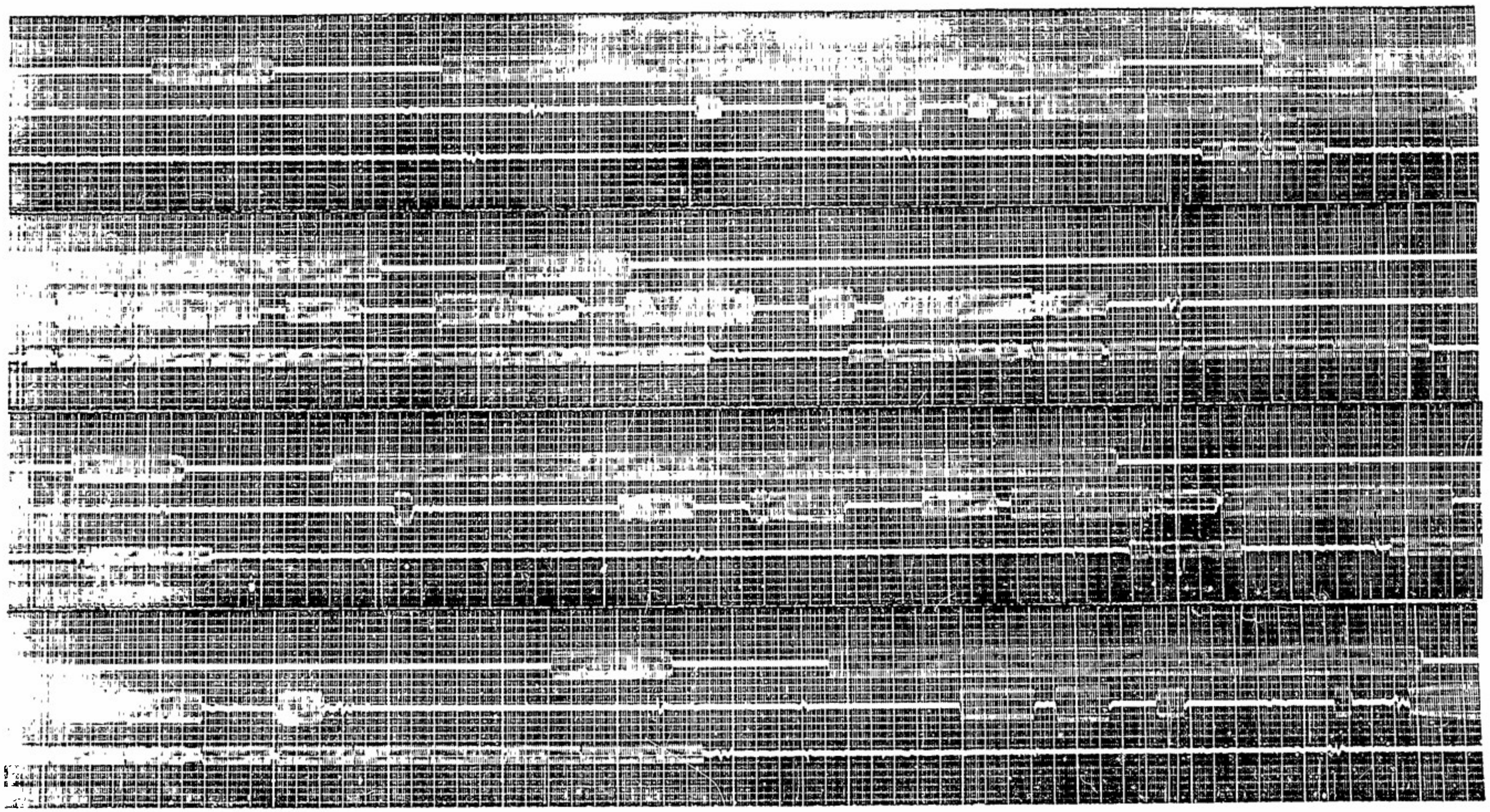

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Fig. 4A - First Half of Word "Paris" - Plain, Scrambled, Restored

1024 14

SECRET

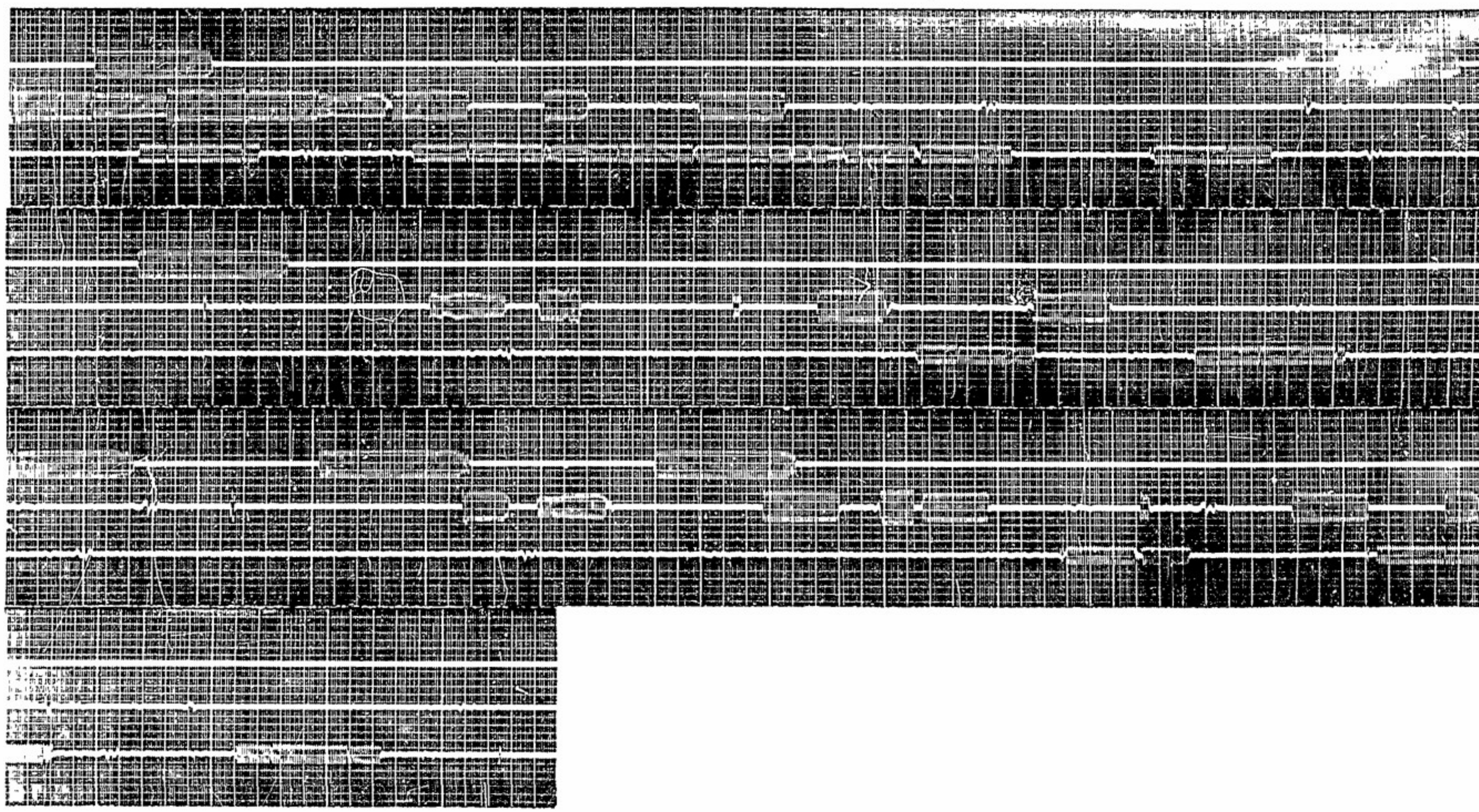
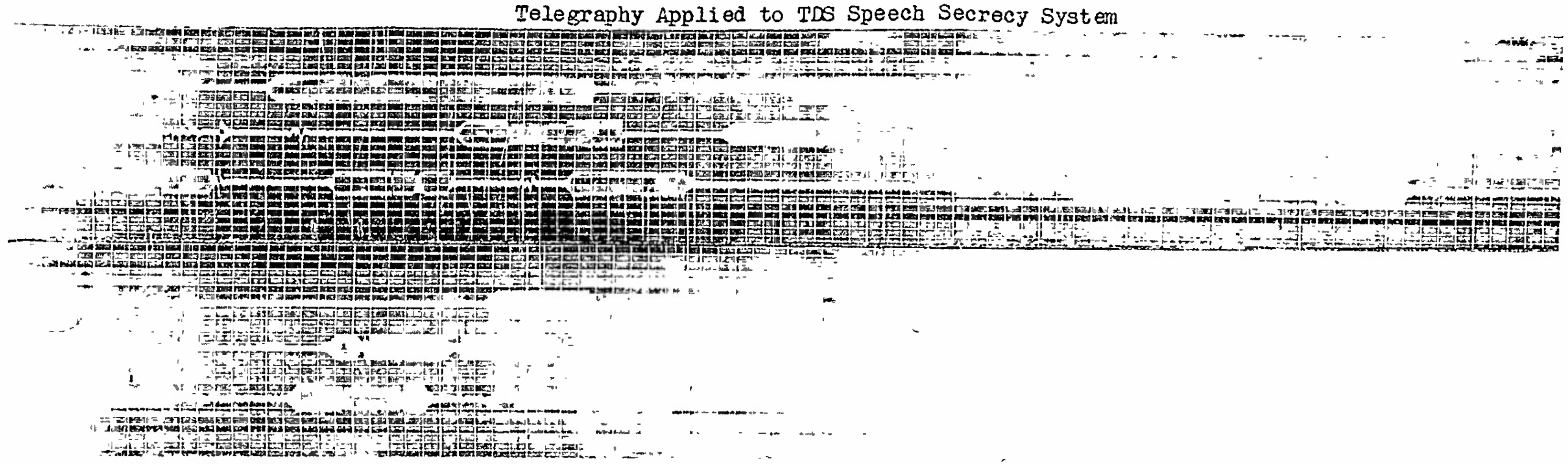


Fig. 4B - Second Half of Word "Paris" - Plain, Scrambled, Restored

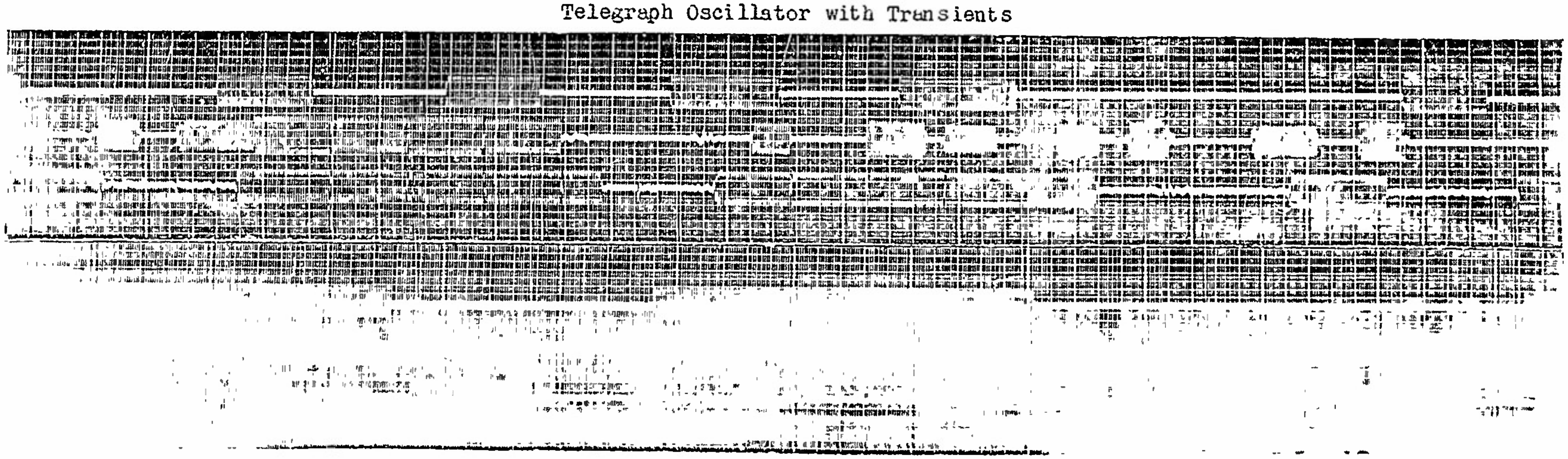
1024 15

N.D.R.C. Project C-55

Telegraphy Applied to TDS Speech Secrecy System



Telegraph Oscillator with Transients



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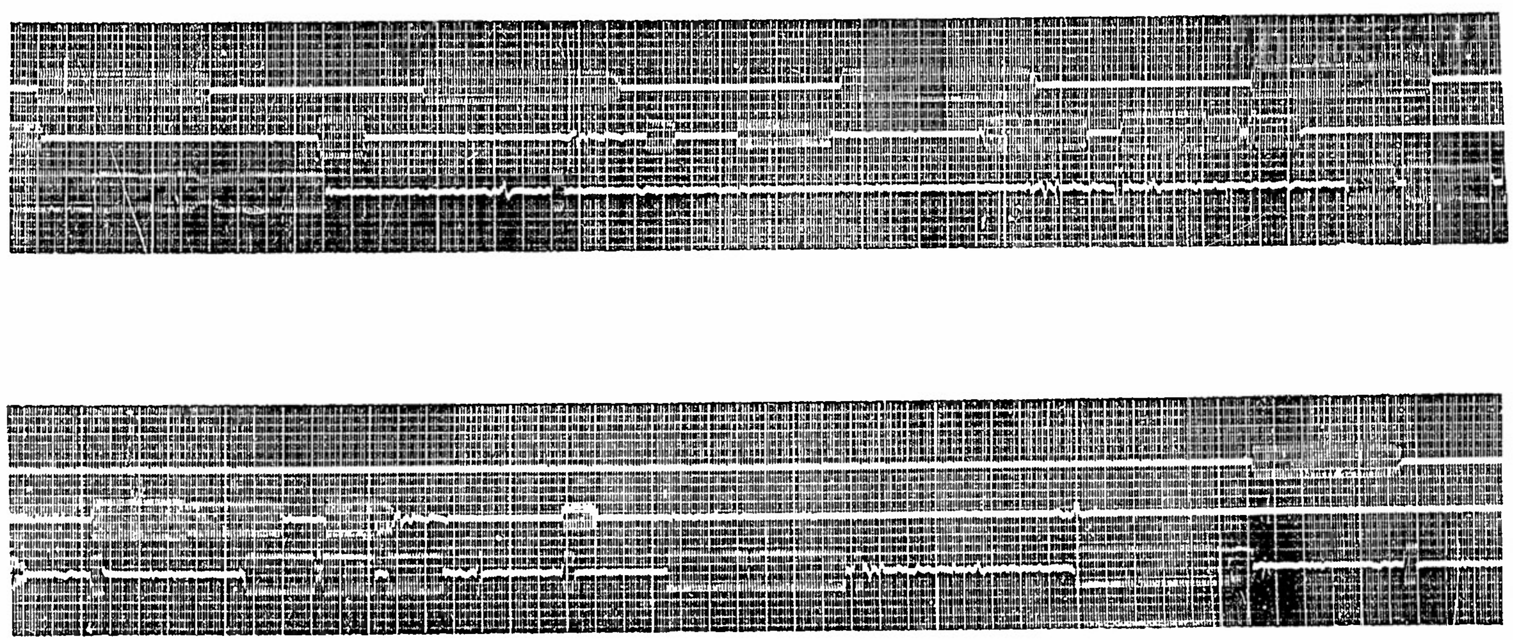
N.D.R.C. Project C-55
Telegraphy Applied to TDS Speech Secrecy System



Effect of Lack of Synchronism
Receiving Unit Lagging by about 15 per cent
of a Commutator Segment

Fig. 6

SECRET

SECRET

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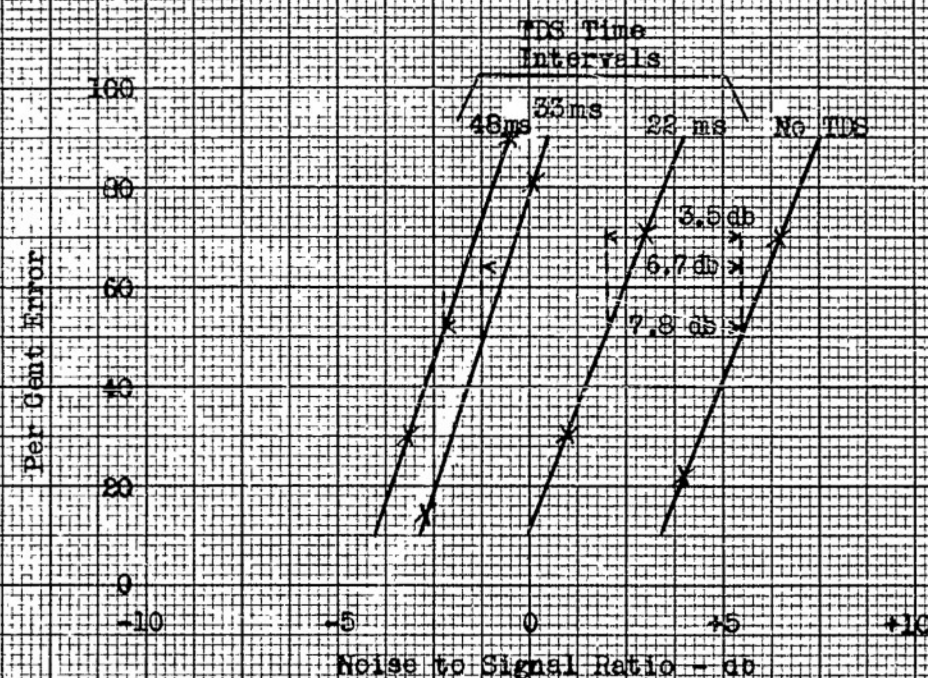
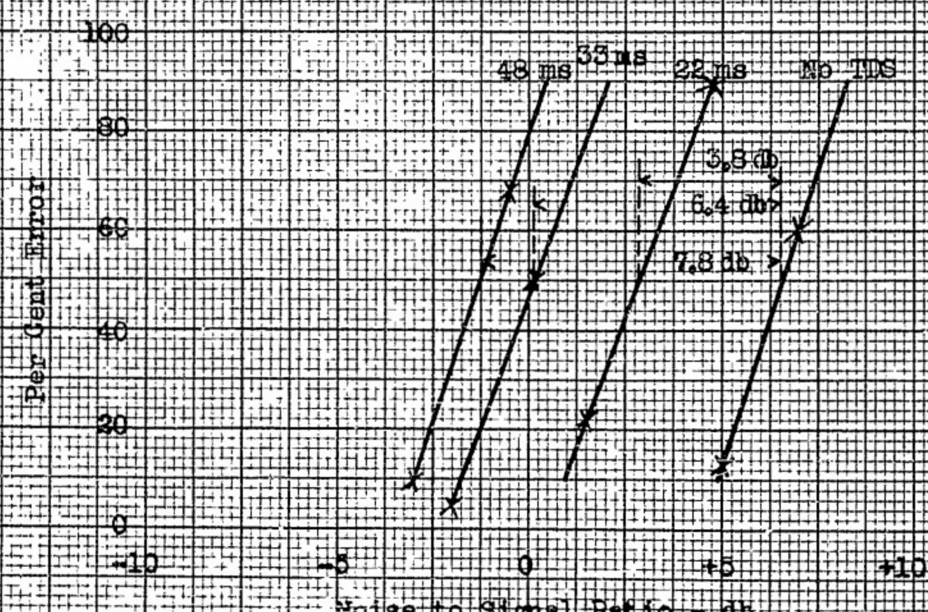
N.D.R.C. Project C-55
Telegraphy Applied to TDS Speech Secrecy System

Effect of TDS Time Intervals
on
Telegraph Transmission Limits

Model B



First Sending

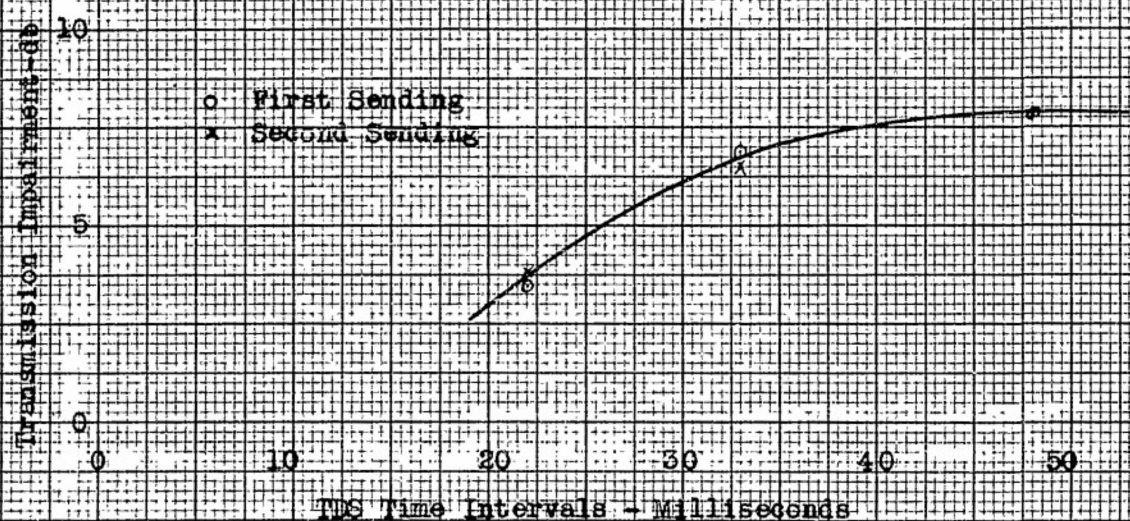


Second Sending

FIG. 7

N.D.R.C. Project C-55
Telegraphy Applied to TDS Speech Secrecy System

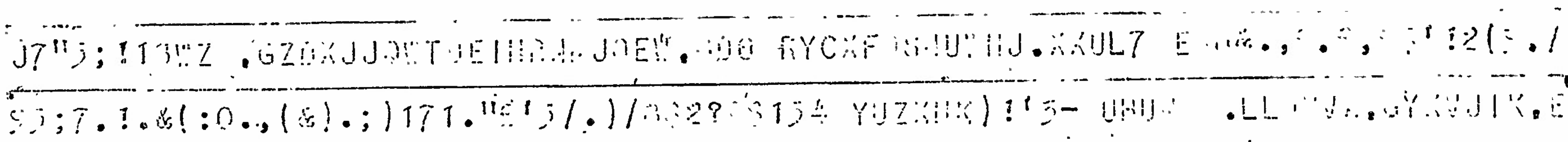
Relation of Transmission Impairment
to
TDS Time Intervals



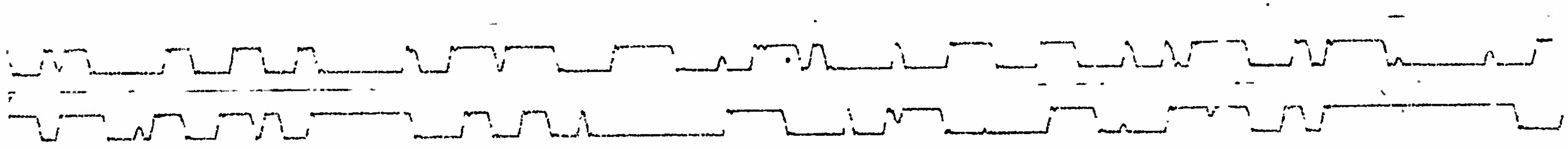
NOTE: Data cross plotted from 50 per cent error points on Fig. 7.

FIG. 8

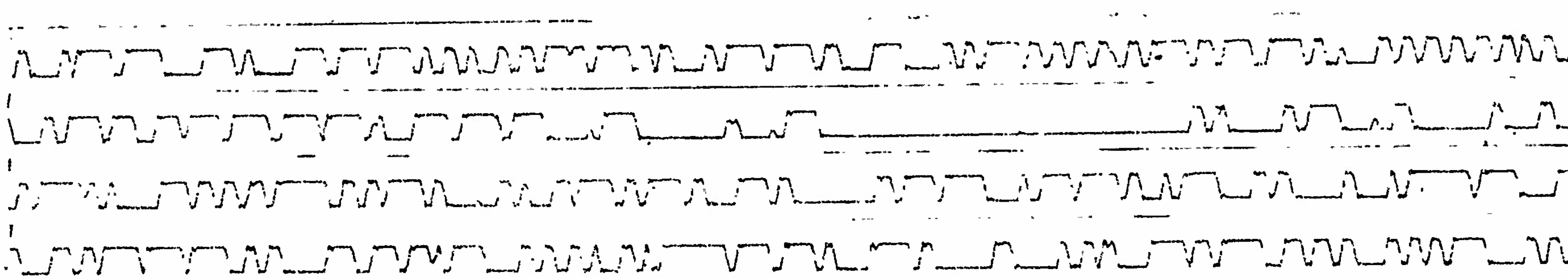
N.D.R.C. Project C-55
Telegraphy Applied to TDS Speech Secrecy System



Teletypewriter - 60 Words Per Minute



Boehme Record of Above Teletypewriter Signal - 60 Words Per Minute



Boehme Signals - 150 Words Per Minute

Fig. 9 - Machine Telegraph Signals Scrambled by Model B TDS
Single Tone

N.D.R.C. Project C-55
Telegraphy Applied to TDS Speech Secrecy System

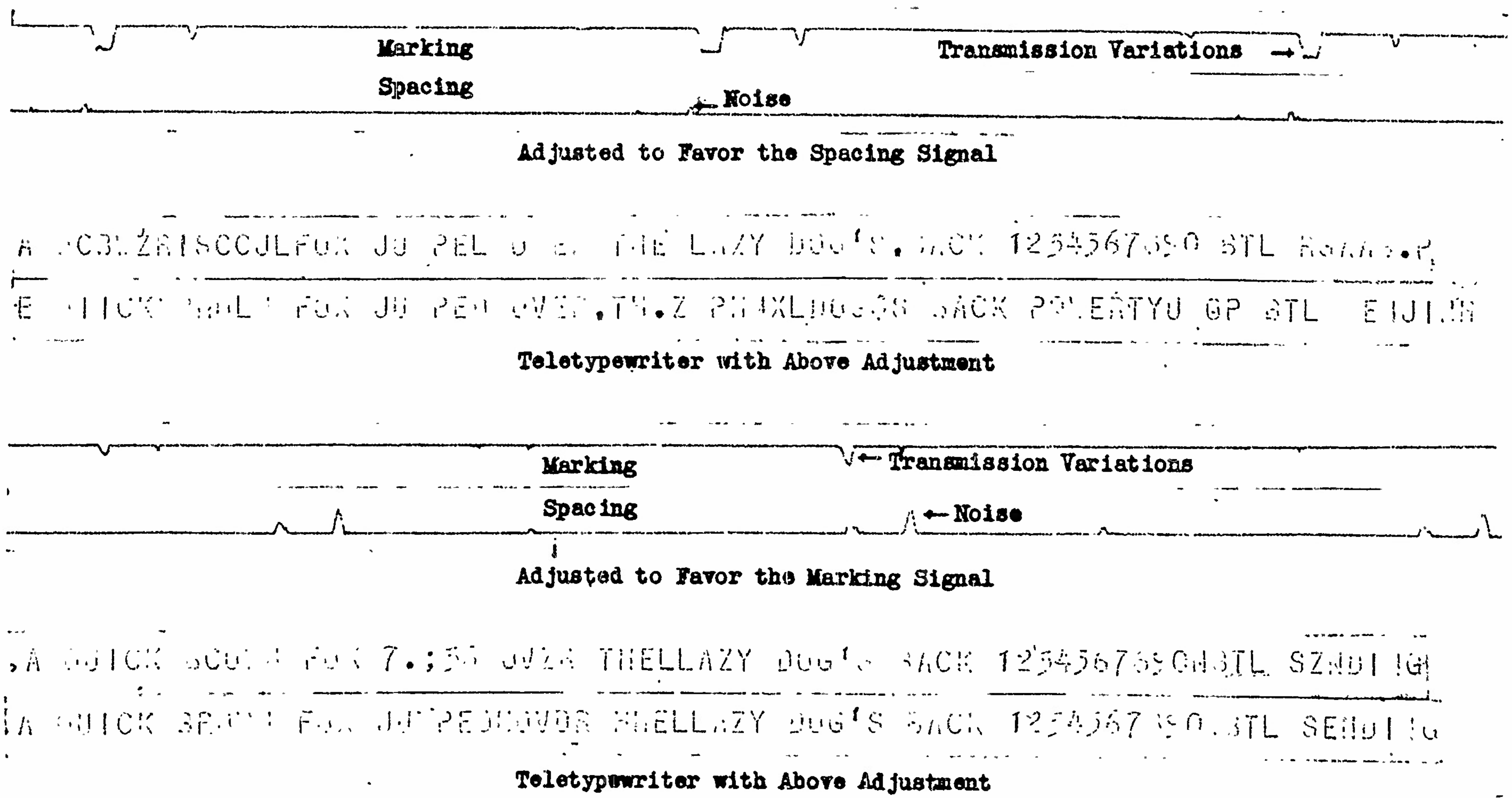
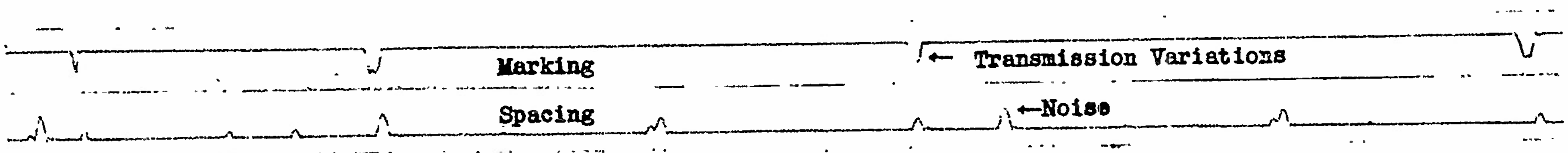


Fig. 10 - Effect of Poor Adjustments of Telegraph Receiving Equipment on Teletypewriter Through TDS - Single Tone

N.D.R.C. Project C-55
Telegraphy Applied to TDS Speech Secrecy System

A QUICK BROWN FOX JU PAD OVER THE LAZY LEG'1 BACF 12&)1(9 0 TL SEND NG...
A CUICK BCOWN FOX JU PED OVER THE LAZY DOG'S ACK 123456789O STL SENDING...

Teletypewriter With Adjustment Shown Below



Balanced Adjustment of Marking and Spacing Conditions

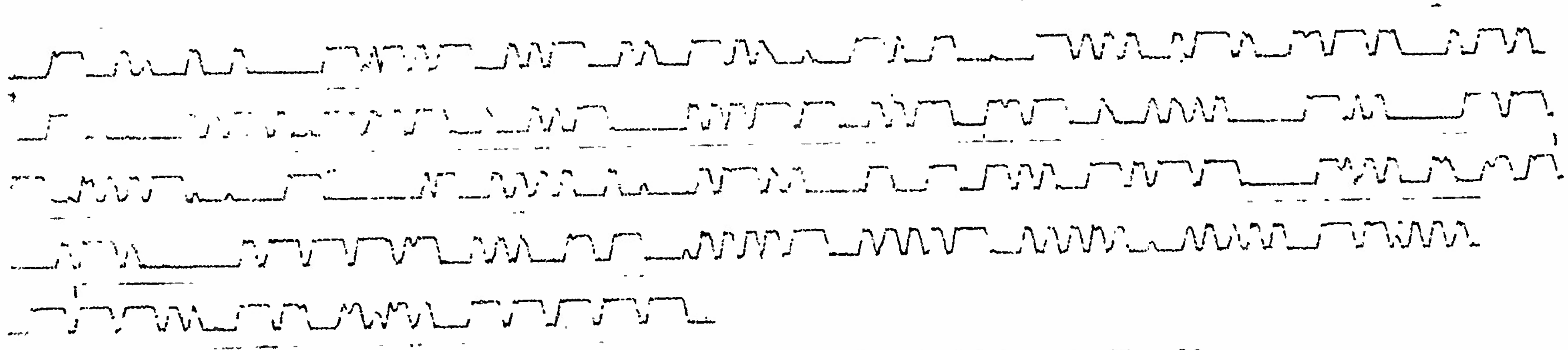
A QUICK BROWN FOX JUMPED OVER THE LAZY DOG'S BACK 123456789O BZL SENDING...
A QUICK BROWN FOX JUMPED OVER THE LAZY DOG'S BACK 123456789O STL SENDING...

Teletypewriter With Above Adjustment and Volume Limiter

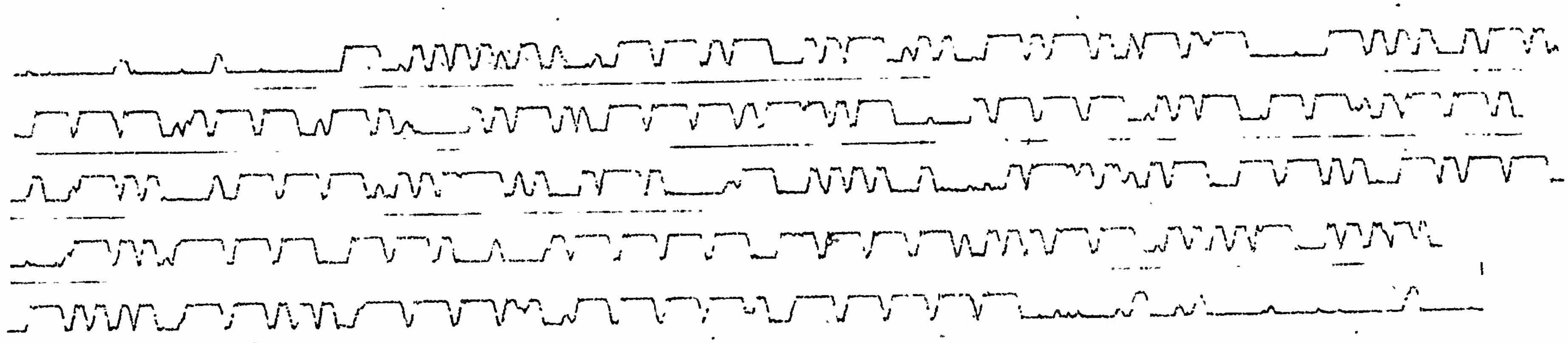
Fig. 11 - Teletypewriter Through TDS Using Balanced Adjustments
60 Words Per Minute - Single Tone

SECRET

N.D.R.C. Project C-55
Telegraphy Applied to TDS Speech Secrecy System



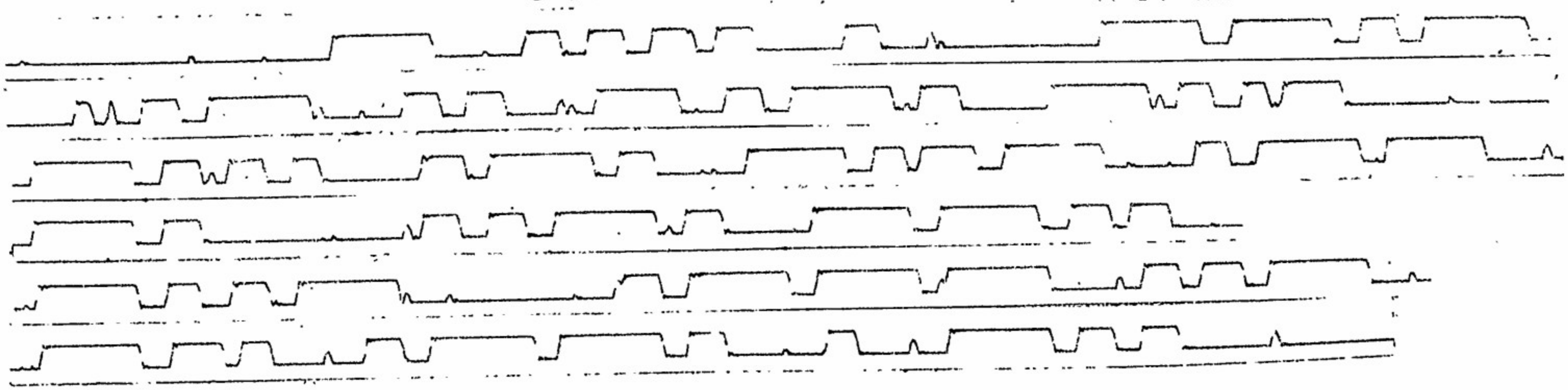
Boehme at 150 w.p.m. with Spacing Signal Favored - See Fig. 10



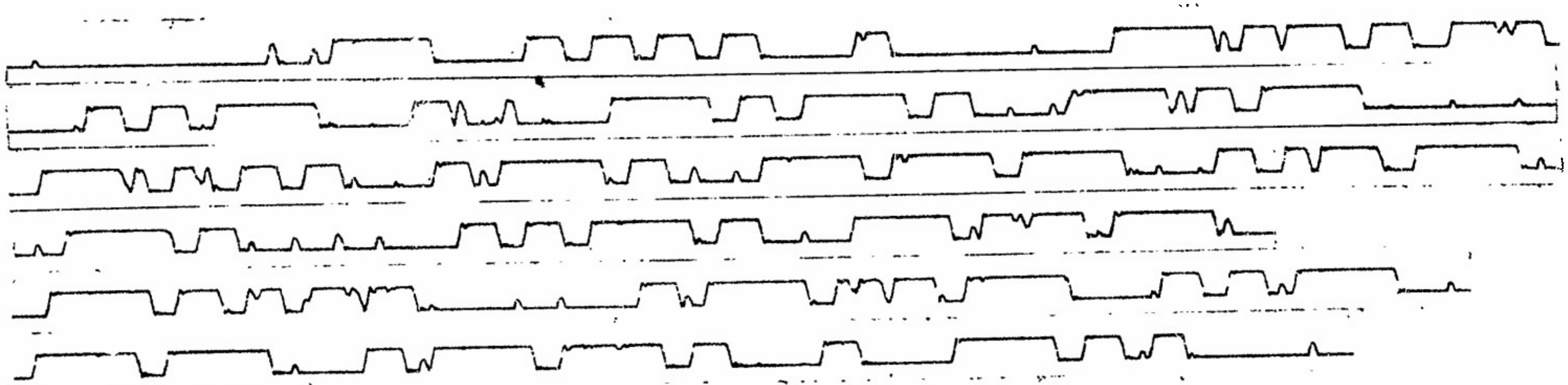
Boehme at 150 w.p.m. with Marking Signal Favored - See Fig. 10

Fig. 12 - Effect of Poor Adjustments of Telegraph Receiving Equipment on Boehme Through TDS - Single Tone

N.D.R.C. Project C-55
Telegraphy Applied to TDS Speech Secrecy System



Boehme at 50 w.p.m. with Balanced Adjustment - See Fig. 11

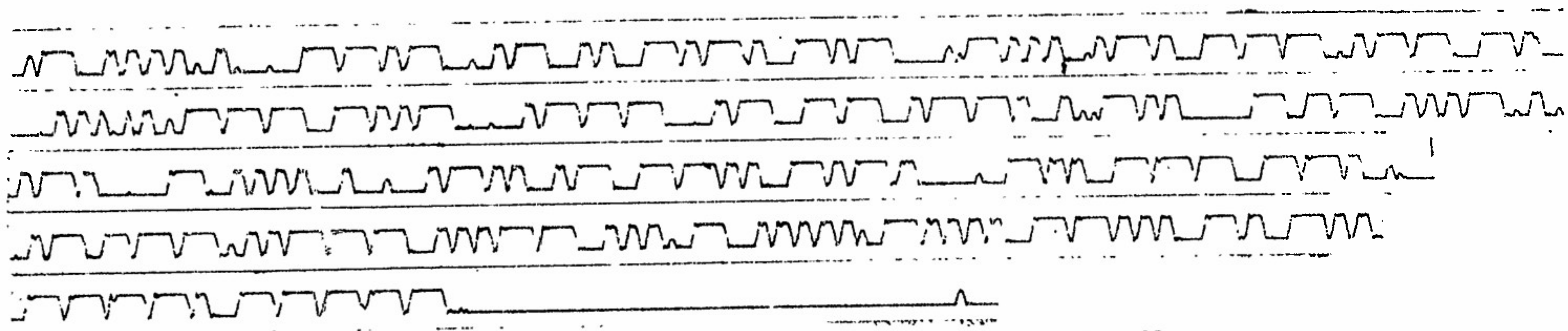


Boehme at 50 w.p.m. with Balanced Adjustment and Volume Limiter

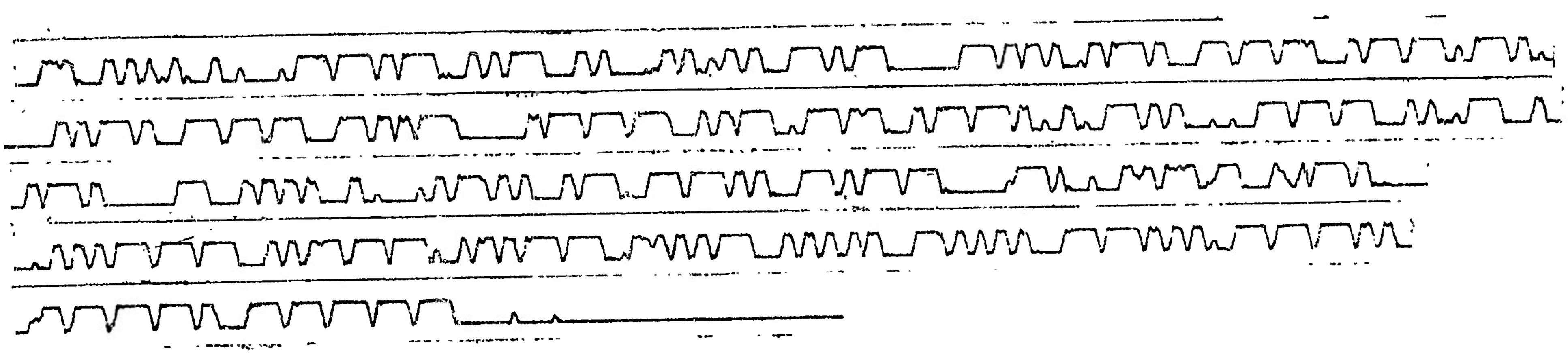
Fig. 13 - Boehme Through TDS Using Balanced Adjustments
50 Words Per Minute - Single Tone

SECRET

N.D.R.C. Project C-55
Telegraphy Applied to TDS Speech Secrecy System



Boehme at 150 w.p.m. with Balanced Adjustment - See Fig. 11



Boehme at 150 w.p.m. with Balanced Adjustment and Volume Limiter

Fig. 14 - Boehme Through TDS Using Balanced Adjustments
150 Words Per Minute - Single Tone

N.D.R.C. Project C-55
Telegraphy Applied to TDS Speech Secrecy System

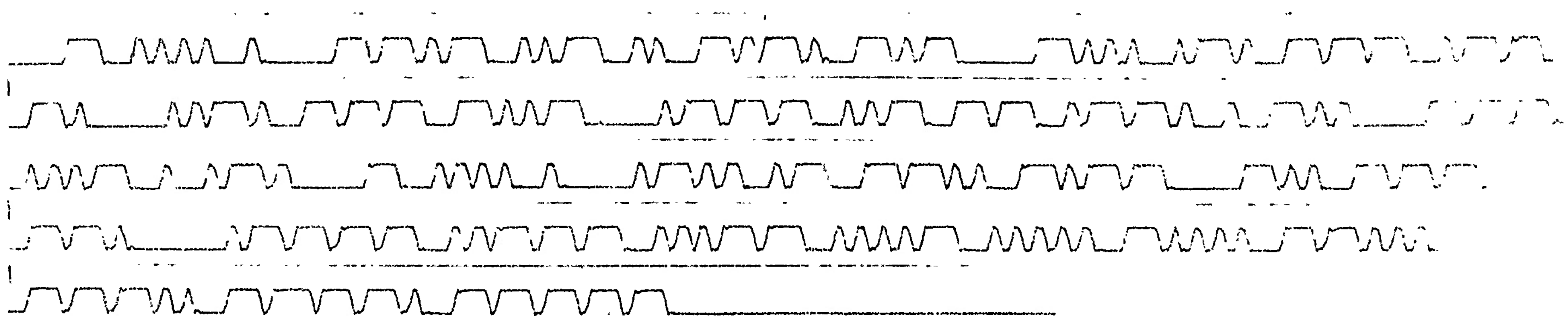


Fig. 15 - Boehme at 150 Words Per Minute Using Two-Tone Telegraphy